Update on e+ Source Modeling and Simulation

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Comparison of positron yield from different undulators

	High K Devices				Low K Devices		
	BCD	**UK I**	**UK II**	**UK III**	**Cornell I**	**Cornell II**	**Cornell III**
Period (mm)	10.0	11.5	11.0	10.5	10.0	12.0	7
K	1.00	0.92	0.79	0.64	0.42	0.72	0.3
Field on Axis (T)	1.07	0.86	0.77	0.65	0.45	0.64	0.46
Beam aperture (mm)	Not Defined	5.85	5.85	5.85	8.00	8.00	
First Harmonic Energy (MeV)	10.7	10.1	12.0	14.4	18.2	11.7	28
Yield(Low Pol, 10m drift)	~2.4	~1.37	~1.12	~0.86	~0.39	~0.75	~0.54
Yield(Low Pol, 500m drift)	~2.13	~1.28	~1.08	~0.83	~0.39	~0.7	~0.54
Yield(60% Pol)	~1.1	~0.7	~0.66	~0.53	~0.32	~0.49	~0.44

Target: 1.42cm thick Titanium

Emittance evolution through undulators

- Tool used: Elegant (a well known beam dynamics code includes synchrotron radiation effects);
- Performed systematic studies using the six undulator parameters;
- Bench marked the energy loss results in undulator against the well known analytical formula.

Beam Parameters and Undulator parameters

- Using the beam parameters at IP, with assumed β function= 40 meters, the beam parameters at undulator can be obtained as (J. Sheppard):

  Sig_x_und=37 microns
  Sig_y_und=2.4 microns
  Sig_xprime_und=0.9 micron-radians
  Sig_yprime_und=0.06 micro_radians

	K	λu(cm)
UK1	0.92	1.15
UK2	0.79	1.1
UK3	0.64	1.05
Cornell 1	0.42	1.0
Cornell 2	0.72	1.2
Cornell 3	0.3	0.7

Elegant simulation results, beam without energy spread (normalized 100 meter undulator length)

The input e- beam parameters: enx is ~ 7.84e-6 and eny is ~ 4.26e-8

- Using the beam parameters at undulator with 0 energy spread:

	Δεnx/εnx (%)	Δεny/εny (%)	ΔE/E (%)	σ_{x_out}	σ_{xp_out}	σ_{y_out}	σ_{yp_out}
UK1	-1.37464	-1.06	-1.3756	9.4259e-5	8.8774e-7	6.4835e-6	6.0111e-8
UK2	-1.10608	-0.912	-1.112	9.4316e-6	8.8907e-7	6.4871e-6	6.0190e-8
UK3	-0.79802	-0.679	-0.804	9.4381e-6	8.9059e-7	6.4908e-6	6.0274e-8
CO1	-0.38277	-0.395	-0.383	9.4464e-6	8.9258e-7	6.4973e-6	6.0398e-8
CO2	-0.77138	-0.652	-0.789	9.4385e-6	8.9070e-7	6.4928e-6	6.0298e-8
CO3	-0.39768	-0.382	-0.399	9.4462e-6	8.9251e-7	6.4972e-6	6.0394e-8

The normalized emittance of drive electron bea damped as a result of radiations in undulators. rate of damping is roughly proportional to the ra of energy lost.

Results with off axis e- beam

- Undulator investigated: UK1, length ~100m. No energy spread

Offset	Δenx (%)	Δeny (%)	$\sigma x_{in}/\sigma x_{out}$	$\sigma y_{in}/\sigma y_{out}$	$\sigma x'_{in}/\sigma x'_{out}$	$\sigma y'_{in}/\sigma x_{out}$
0,10μm,50μm	-1.37	-1.06	2.99e-5 /9.42e-5	2.40e-6 /6.48e-6	9e-7 /8.93e-7	6.05e-8 /6.01e-8
1mm in x	-1.59	-1.13	2.99e-5 /9.40e-5	2.40e-6 /6.48e-6	8.94e-7 /8.83e-7	6.05-8 /6.01e-8
1mm in y	-1.59	-1.14	2.99e-5 /9.42e-5	2.40e-6 /6.46e-6	8.94e-7 /8.88e-7	6.05e-8 /5.98e-8

$$Bx = -|B0|\Sigma_{m,n} Cmn \cosh(k_{xl}x) \cos(k_{ym}y) \cos(k_{zn}z + \theta_{zn}),$$

$$By = -|B0|\Sigma_{m,n} Cmn \cos(k_{xl}x) \cosh(k_{ym}y) \cos(k_{zn}z + \theta_{zn}),$$

Off-axis beam sees stronger fields and thus radiated more photons.

Result with energy spread at different undulator length

- Undulator investigated: UK1, 25MeV sigma of energy spread,
- *Surprise: Vertical damping does not scale vs undulator length.*

configuration	Δεnx/εnx (%)	Δεny/εny (%)
~100m	-1.36	-1.18
~200m	-2.69	-1.27
~300m	-3.93	0.84

These results can be explained by an analytical approach with some approximations (from Kwang-Je Kim): (1)

$$\Delta\varepsilon_n = -\varepsilon_n \frac{|\Delta E|}{E} + (\beta_0 + \frac{L^2}{3\beta_0}) \frac{K}{\gamma} \frac{1}{E^2} \frac{\hbar\omega_{max}}{2} |\Delta E|$$

where the first term on the right is the damping effect and the 2nd term is the excitation. For 100m RDR baseline undulator (UK1), the damping/excitation ratio can be obtained using equation (1) as 3 in vertical and 600 in horizontal.

Comments on the Quads-BPMs and Wakefields

- Duncan Scott and James Jones have studied the effect of transverse resistive wall wakefields of undulator beam tube and the optics. They found that the kick from wakefields is very small and the emittance growth is due to the optics. Their study shows that 10um resolution in BPM-Quad will result in ~8% emittance growth in vertical plane.
- Kiyoshi Kubo from KEK has reported a study on the effect of BPM-Quad misalignment and the synchrotron radiation from undulator. He reported that the effect of undulator radiation and QUAD-BPM misalignment on the emittance growth can be tolerated.
- Our initial studies qualitatively in agreement with their studies, but we need further study to be sure.

Future plans

- Integrate Feng's (SLAC) elegant simulation with ours work for modeling e+ source from start to end.
- Complete the emittance evolution simulation with QUAD-BPM misalignment.
- Collaborating with other groups on e+ source related topics like liquid target, lithium lens, spinning target under magnetic field, compton scheme, etc.

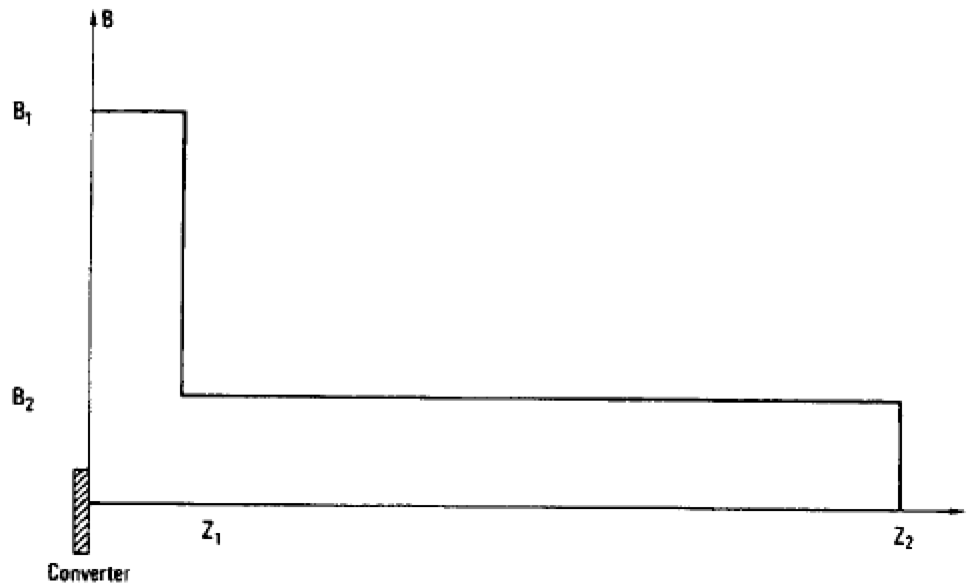
Materials from the last meeting.

OMD studies

- K=0.92, λu=1.15cm, 100m long
- 0.4rl Ti target
- Gradient and aperture in comply with RDR
- Drift to target 450m
- OMD compared:
  - Immersed target (6T-0.5T in 20 cm)
  - Non immersed target (0-6T in 2cm, 6T-0.5T 20cm)
  - Quarter wave transformer
  - Back ground solenoid only
  - Lithium lens

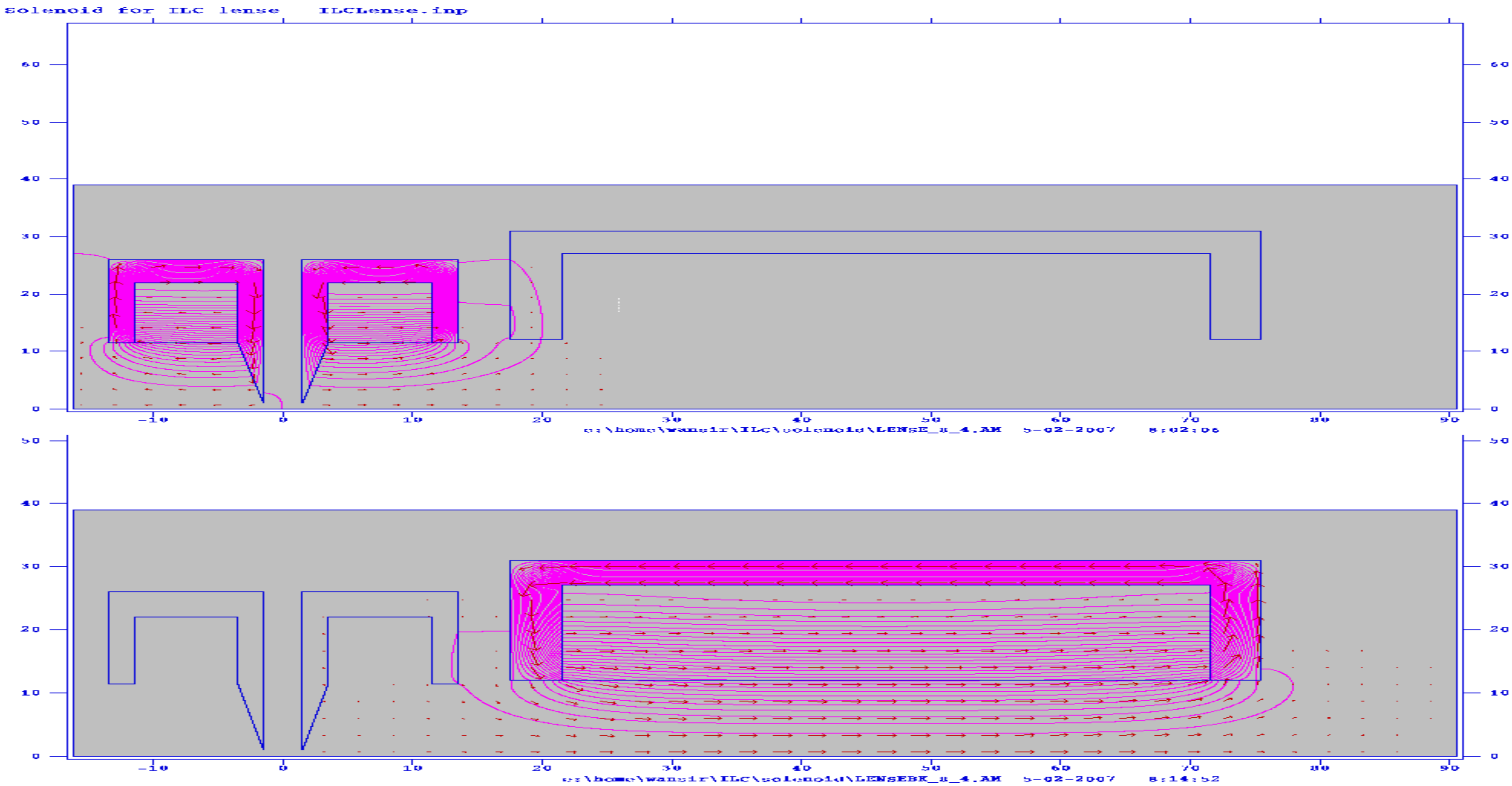
Quarter wave transformer simulation

a short lens with a high magnetic field and a long solenoidal magnetic field.

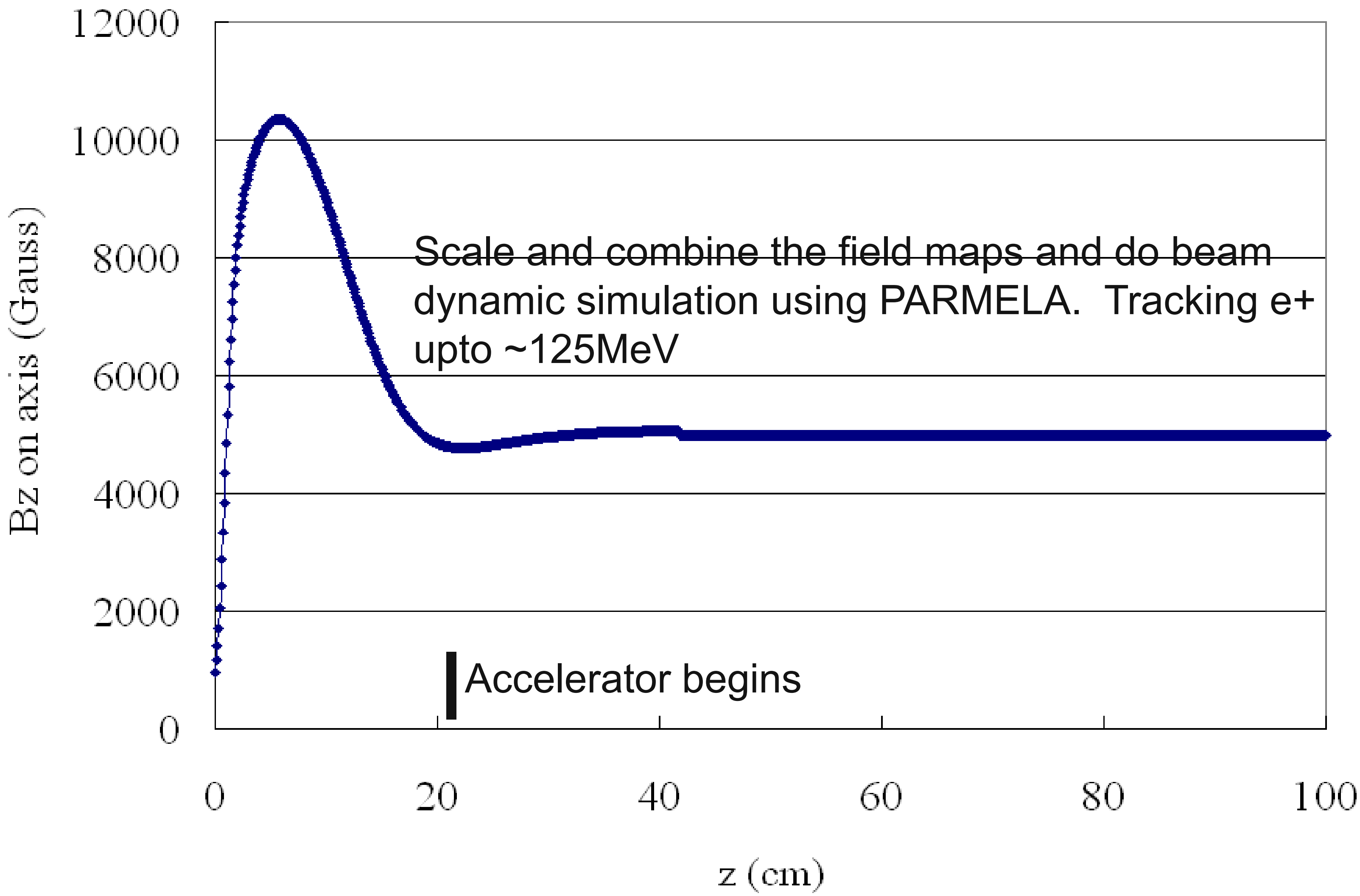


Field profile of quarter wave transformer

Magnetic field profile: Superposition of two field maps.

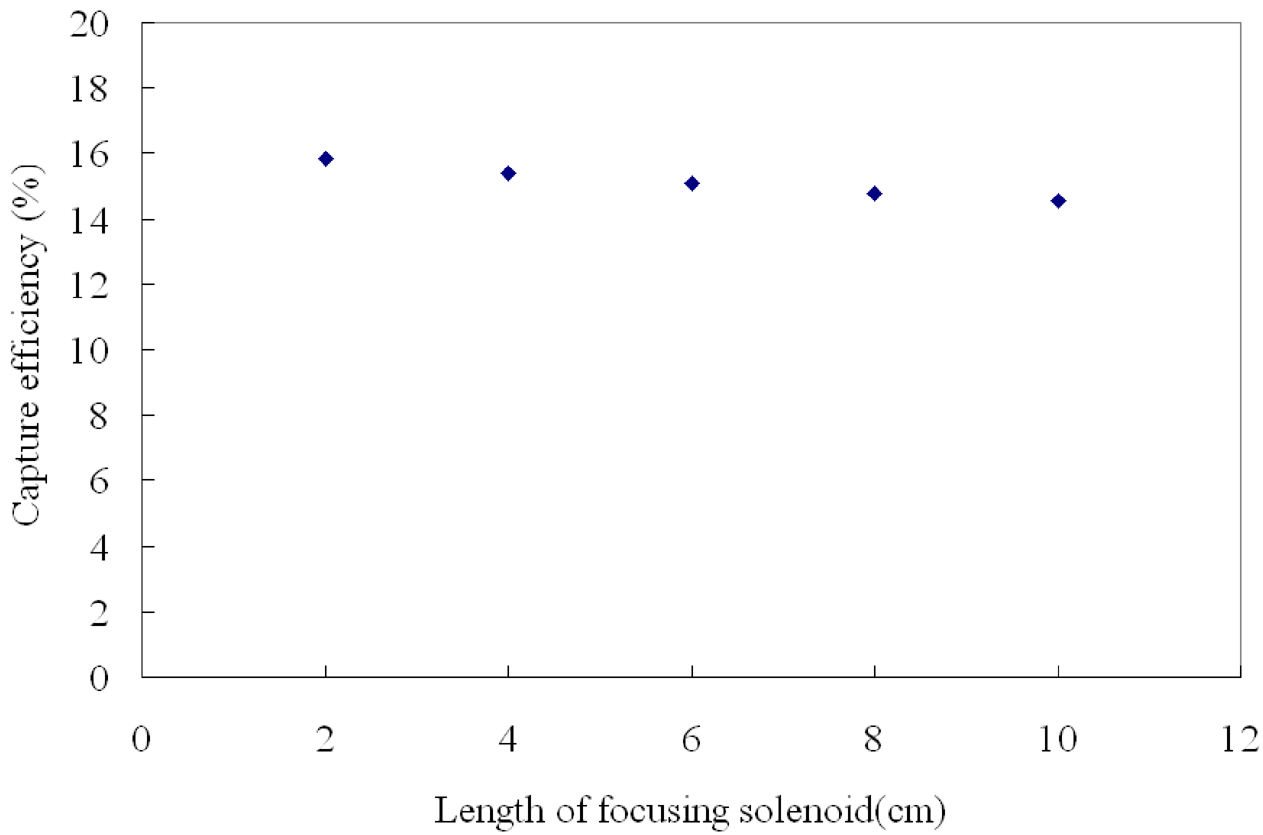


On axis Bz profile

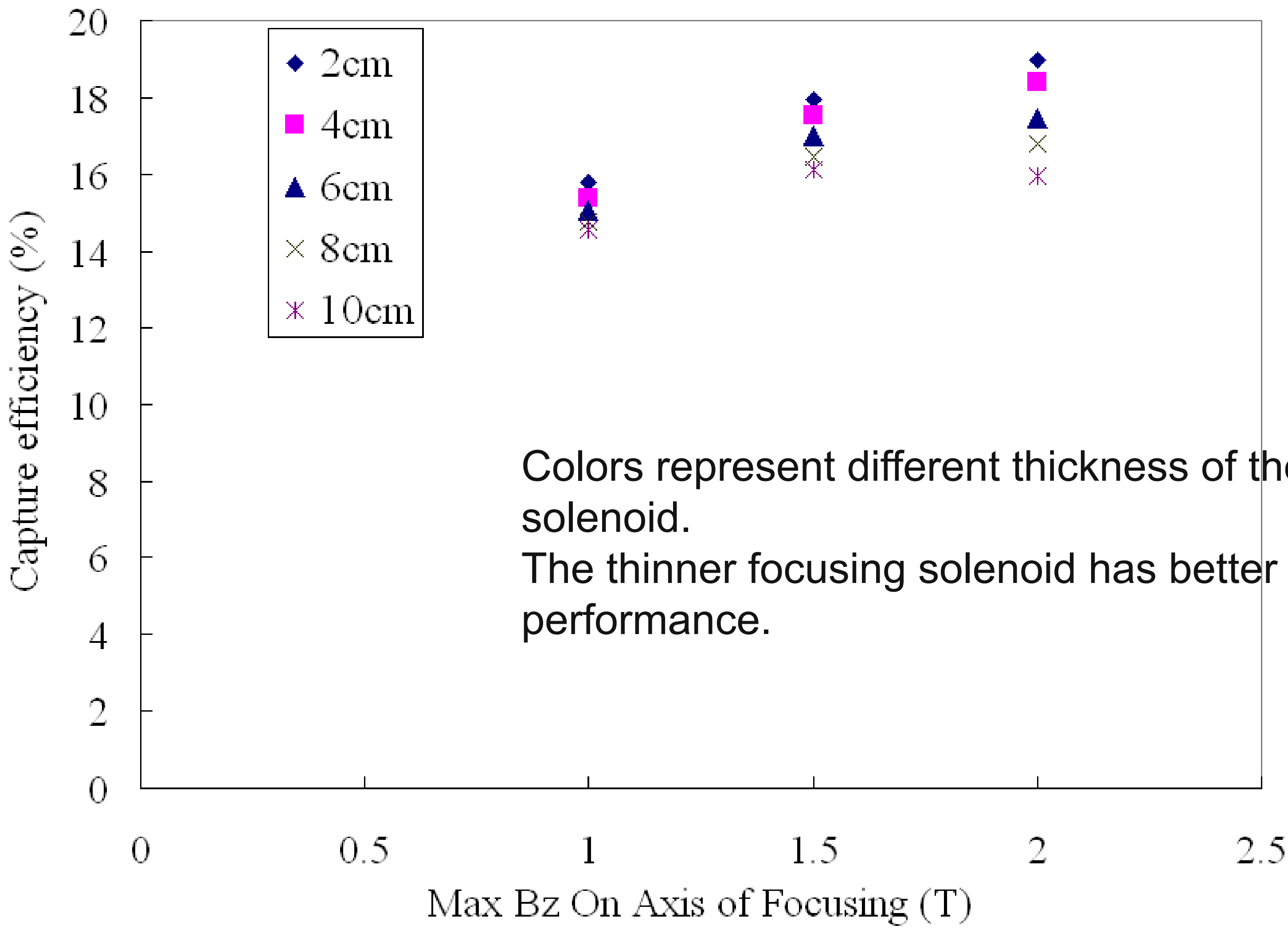


Scale and combine the field maps and do beam dynamic simulation using PARMELA. Tracking e+ upto ~125MeV

Capture efficiency as function of length of focusing solenoid. Max B field on axis is ~1T. Gap between bucking and focusing is at 2cm. Separation between focusing and matching is 0.

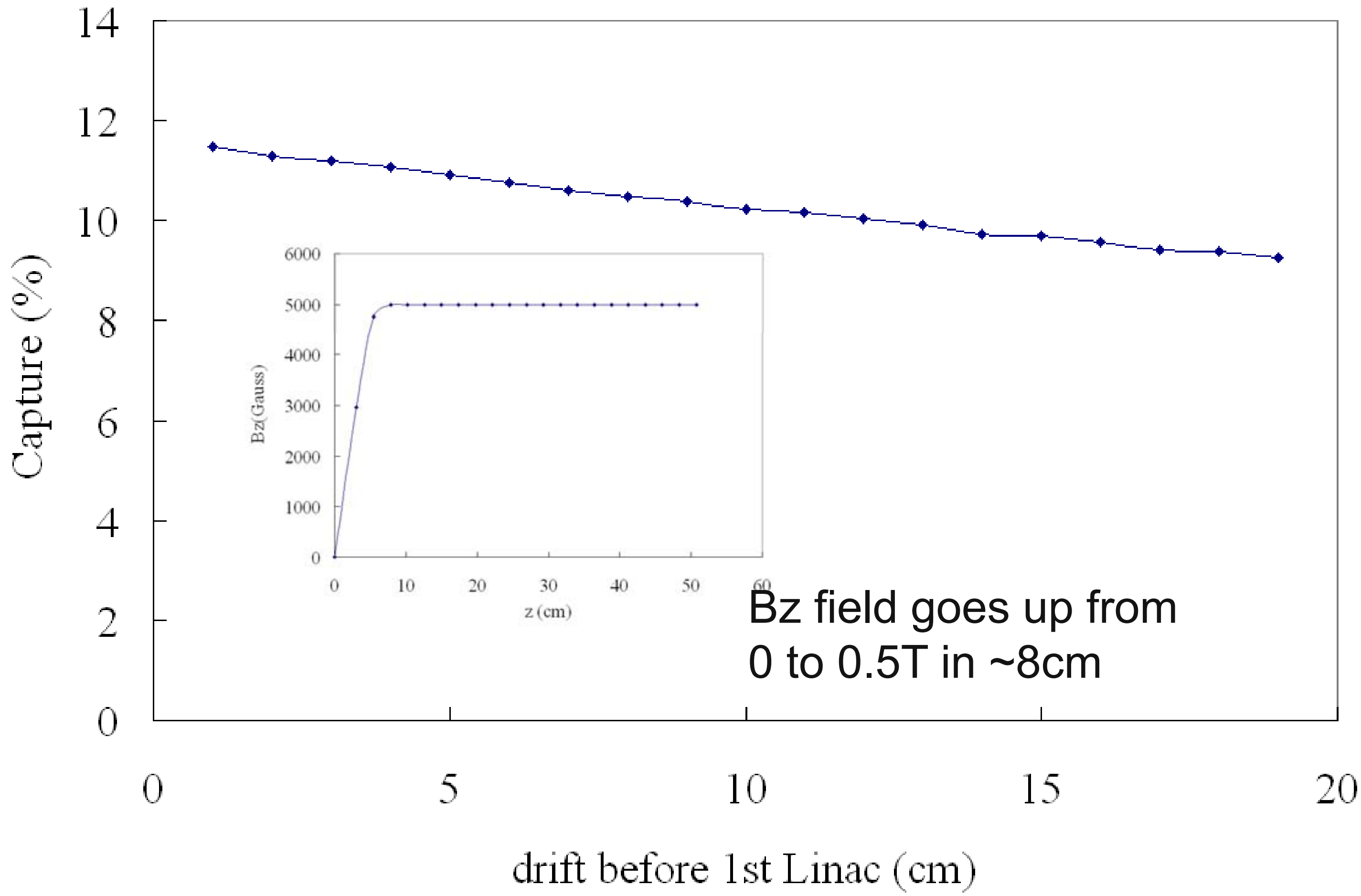


Capture as function of focusing field



Colors represent different thickness of the focusing solenoid.
The thinner focusing solenoid has better performance.

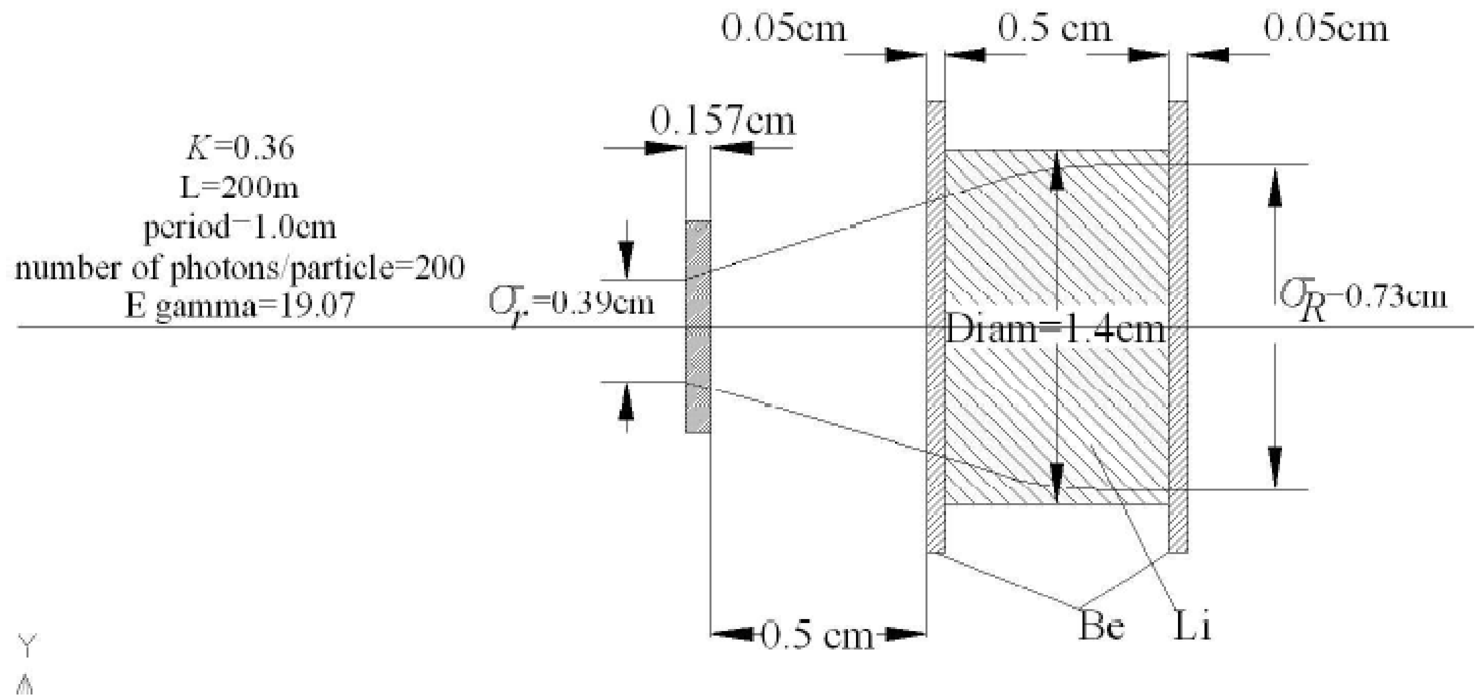
Capture efficiency with only 0.5T background solenoid



A.M. Aug 20, 2007

TARGET AND LENS

Shown below is W target



Total current in lens =156 kA. Be and Li stay in good thermal contact. Lithium is liquid and runs ~10m/sec.

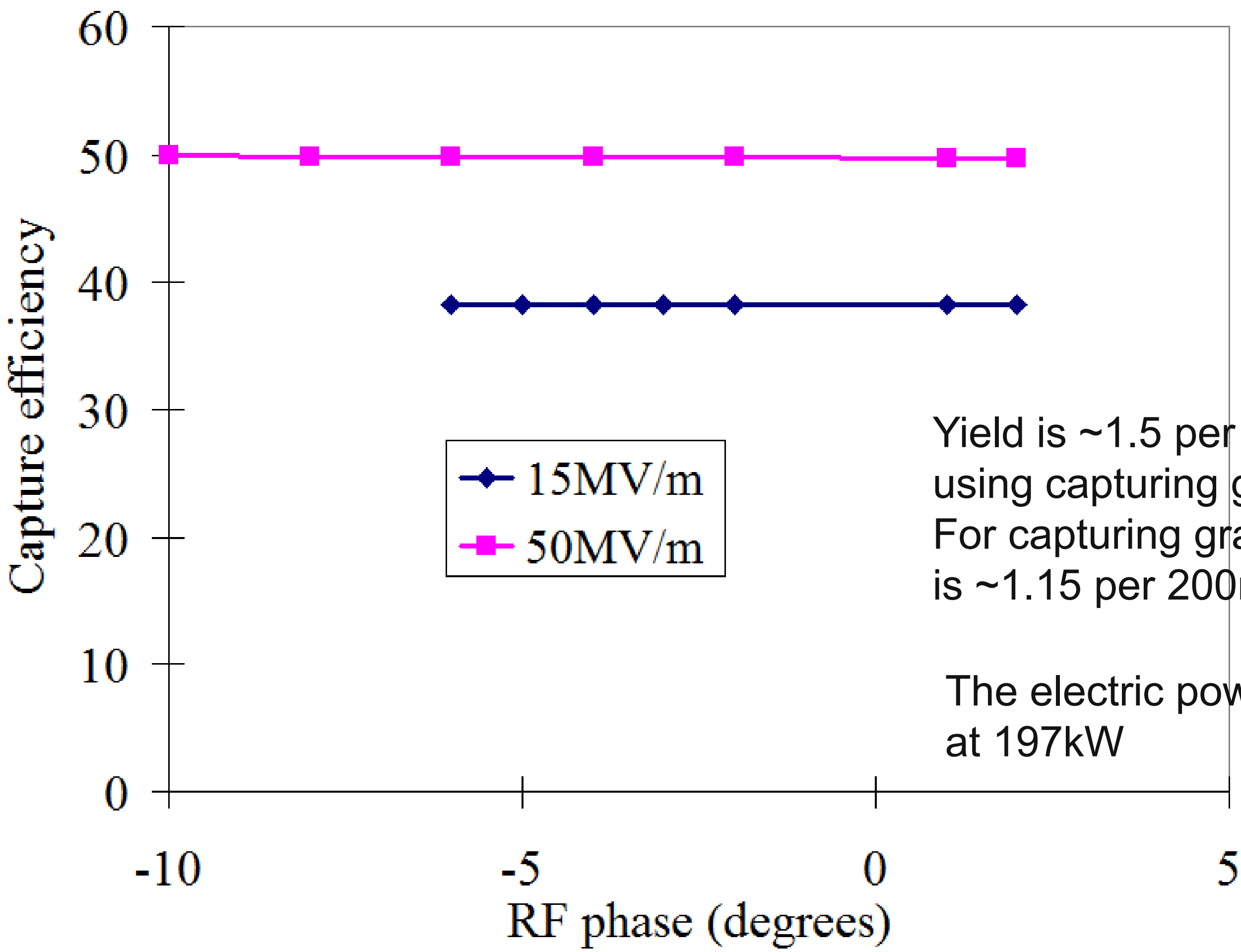
Shown is beam envelope with R.M.S. values.

Efficiency of conversion is 1.68.

Conditions:

- Undulator: k=0.36, λu=1.0cm, length:200m
- Drift to target: 350m
- Drive beam energy: 150GeV
- Capture: at ~125MeV, using +/-7.5 degree phase cut, $\varepsilon x+\varepsilon y$ <0.09m.rad, energy spread +/-25MeV.
- Capturing RF gradient: 15MV/m and 50MV/m
- Assume uniform current distribution in lithium lens

Yield and capture efficiency



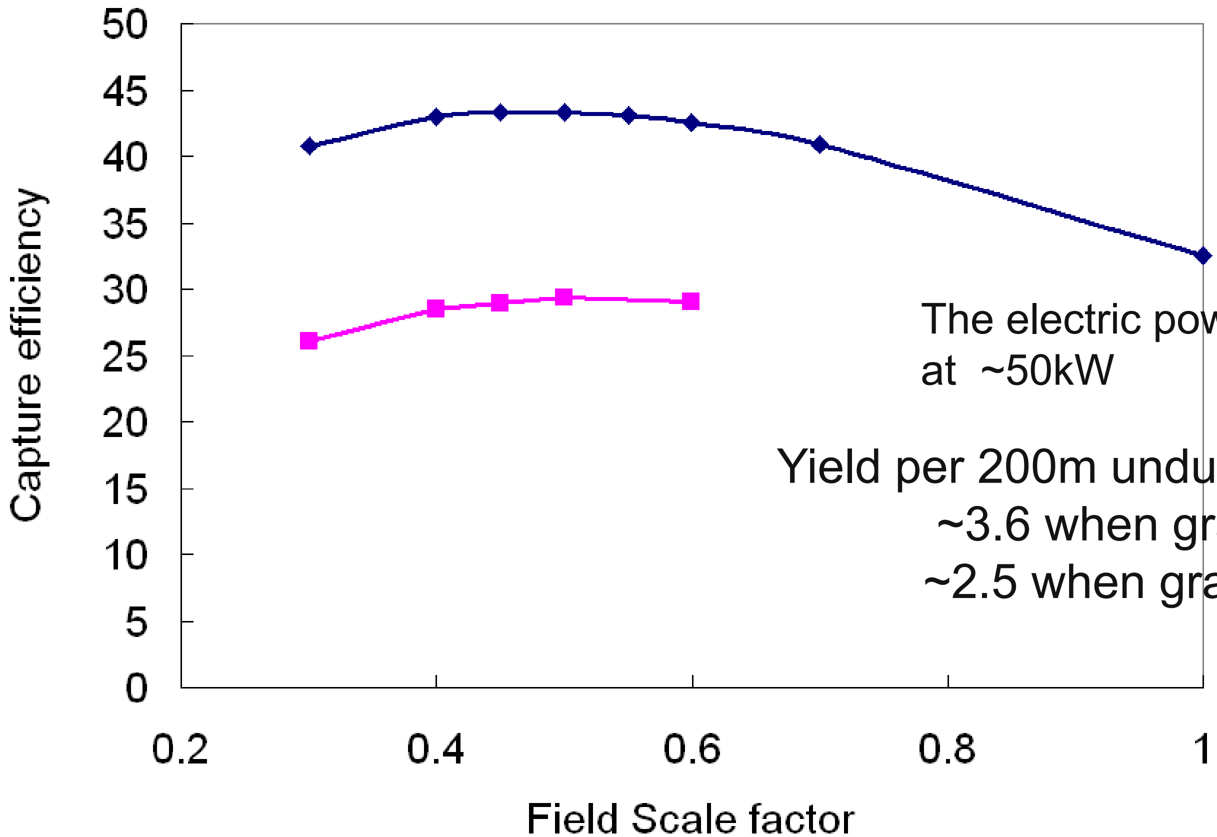
Yield is ~1.5 per 200m undulator when using capturing gradient of 50MV/m
For capturing gradient of 15MV/m, the yield is ~1.15 per 200m undulator

The electric power required is estimated at 197kW

Using baseline undulator and target with Lithium lens

- Undulator: K=0.92, λu=1.15cm, 100m
- Titanium target:0.4 rl
- Drift to target: 450m
- Drive beam energy: 150GeV
- Capture: at ~125MeV, using +/-7.5 degree phase cut, $\varepsilon x+\varepsilon y$ <0.09m.rad, energy spread +/-25MeV.
- Capturing RF gradient: 50MV/m

Yield and capture efficiency using baseline undulator and target with lithium lens



The electric power required is estimated at ~50kW

Yield per 200m undulator:
~3.6 when gradient is 50MV/m
~2.5 when gradient is 15MV/m

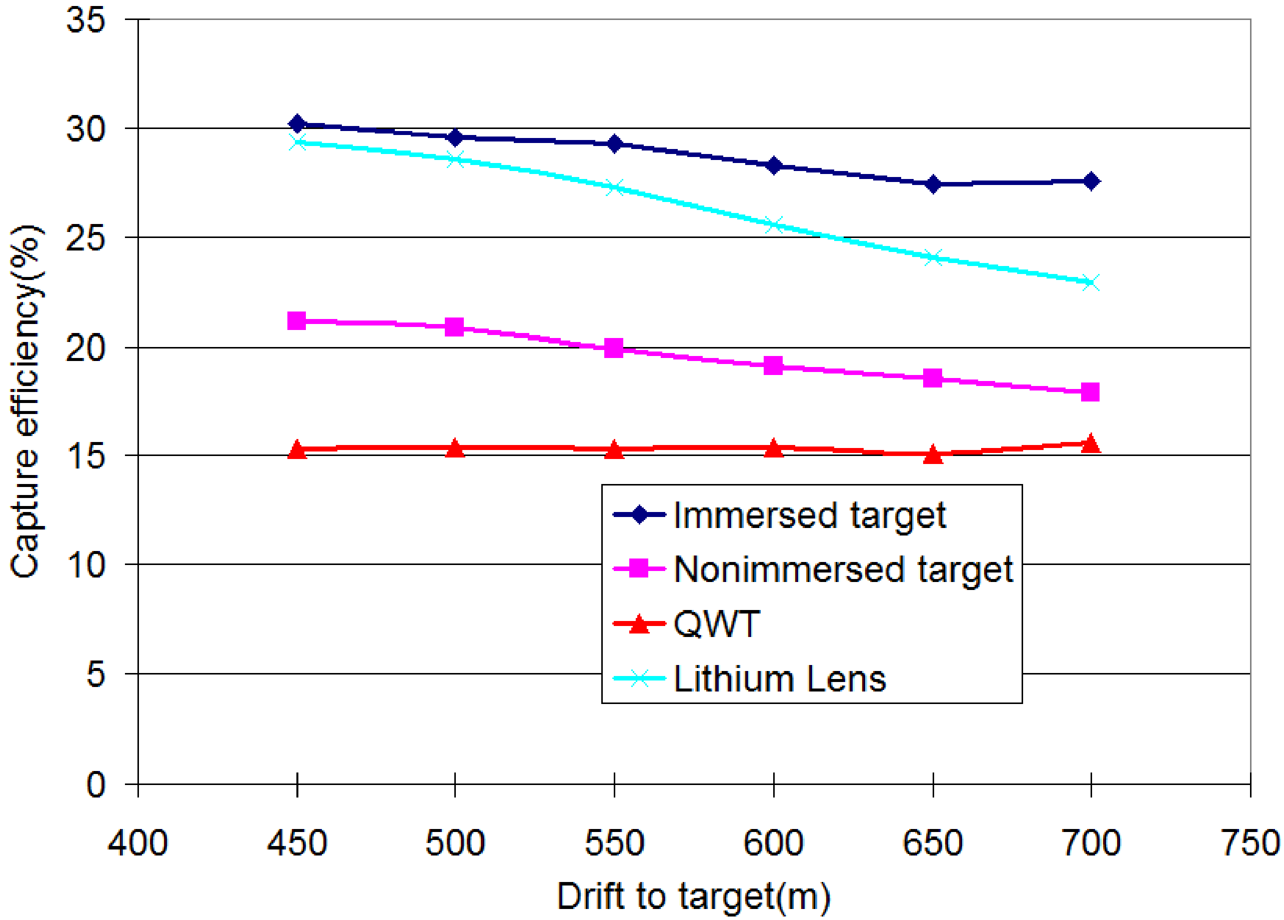
Capture Efficiency of Different OMD

OMD	Capture efficiency
Immersed target (6T-0.5T in 20 cm)	~30%
Non-immersed target (0-6T in 2cm, 6T-0.5T 20cm)	~21%
Quarter wave transformer (1T, 2cm)	~15%
0.5T Back ground solenoid only	~10%
Lithium lens	~29%

3. The effect of spot size on positron capture efficiency

- 100m undulator, K=0.92, λu=1.15cm
- Target: Ti, 0.4 rl
- Drift to target: from 450m up to 700m(spot size: 1.5mm up to 2.3mm)
- Immersed case: 6T-0.5T, 20cm
- Non Immersed case: ramp(0-6T) 2cm, 6T-0.5T 20cm
- Quarter wave transformer: 1T-0.5T, 2cm DC coil

Capture efficiency as function of spot drift to target (spot size)



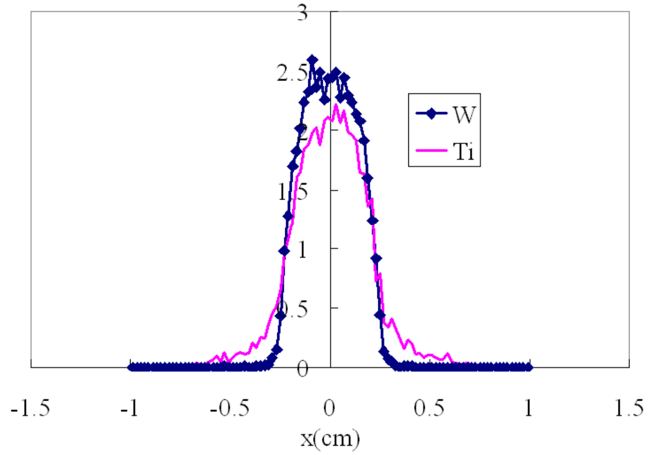
Capture efficiency lowered by 10% for immersed target when spot size increased from σ ~1.5mm up to ~2.3mm.
For non immersed case, the capture efficiency dropped by ~ 14%.
For quarter wave transformer, the capture efficiency doesn't change with spot size within the range of 1.5mm to 2.3mm
For lithium lens,

4. Comparing Tungsten target and Titanium target

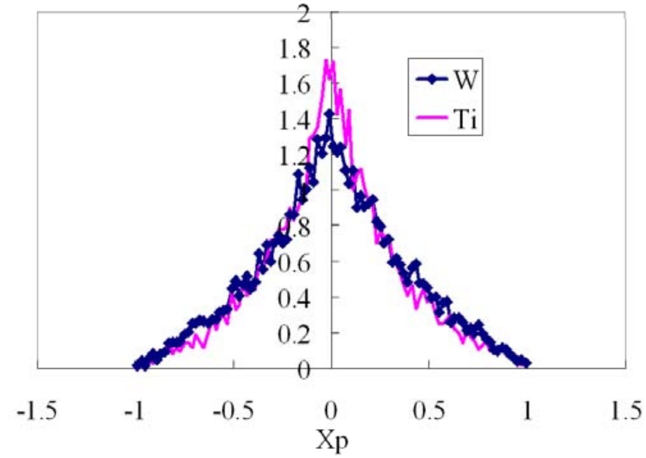
- Same undulator
- Same target length (measured in radiation length)
- Same beam line
- Same collimator settings

Tungsten target gives about 50% higher raw yield in positron production but the captured yield only enhanced by ~10% due to broader divergence distribution of e+ produced in tungsten target.
The density of deposited energy in tungsten target is about 10 times higher than titanium target.

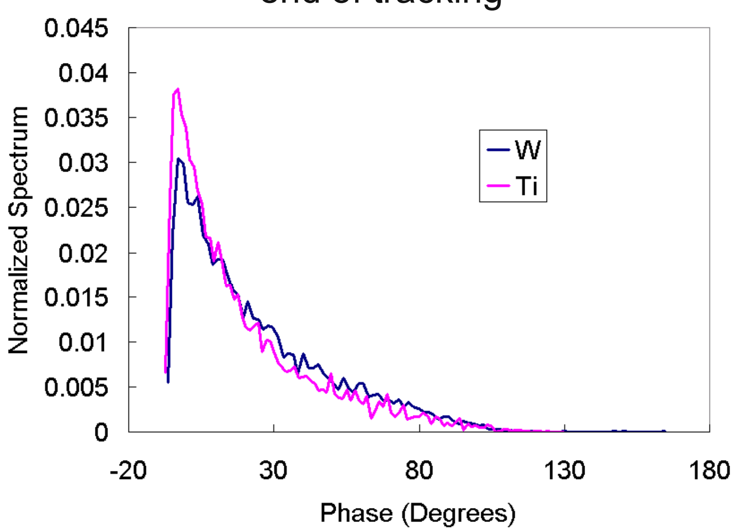
Normalized transverse distribution of e+ when exiting from target



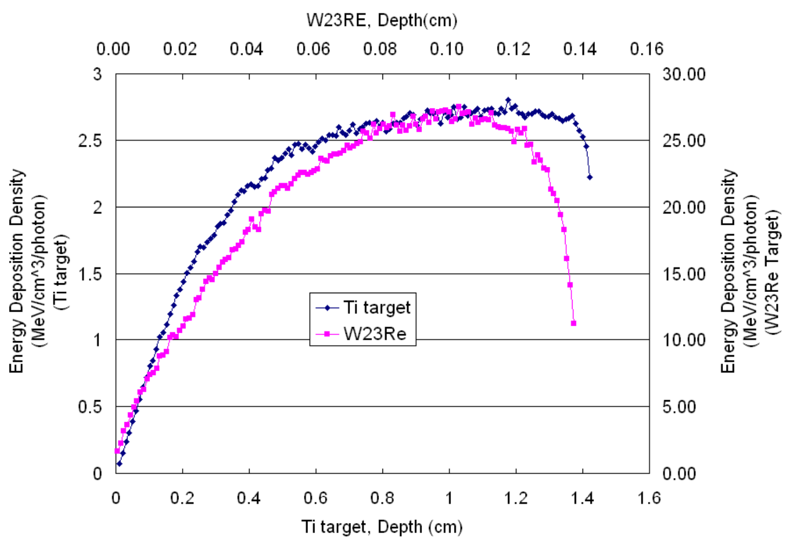
Normalized divergence distribution of e+ when exiting from target



Normalized longitudinal distribution of e+ at end of tracking



On beam axis profile of deposit energy density



Summary

- Comparing the capture efficiency, lithium lens has about the same efficiency as immersed AMD
- Increase the spot size will lower the capture efficiency except for quarter wave transformer. The exactly trade off need to be determined.
- Tungsten target can give ~50% more on raw yield. But given the same in put condition, the density of energy deposition for tungsten target is 10 times higher than for titanium target. And due to the wider divergence distribution of e+ from tungsten target, the enhancement to e+ yield will be limited
- Emittance of drive electron beam will be damped as a result of radiation. The emittance growth due to wakefield is very small and ignorable based on Duncan's result.